

1 METHOD, APPARATUS AND SYSTEM FOR PILOTLESS FREQUENCY OFFSET
2 COMPENSATION IN MULTIPONT-TO-POINT WIRELESS SYSTEMS WITH OFDM

3

4 This application is related to co-invented, co-owned U.S.
5 Serial Nos. 10/342,519 filed Jan. 15, 2003, 10/406,776 filed
6 April 3, 2003, 10/628,943 filed July 29, 2003, and 10/638,980
7 filed Aug. 12, 2003, all of which are hereby incorporated by
8 reference herein in their entireties.

9

10 BACKGROUND OF THE INVENTION

11

12 1. Field of the Invention

13 The present invention relates broadly to
14 telecommunications and data transmission via multiple
15 telecommunication channels. The present invention more
16 particularly relates to wireless telecommunication systems
17 operating in radio channels with variable parameters.
18 Specifically, the invention relates to multipoint-to-point
19 (MPTP) wireless systems and networks with multicarrier
20 orthogonal frequency division multiplexing (OFDM).

21

22 2. State of the Art

1 OFDM technology has well-known uses in a wide variety of
2 wire and wireless telecommunication systems. The OFDM
3 technique distributes and transmits data synchronously over a
4 large number of carriers that are spaced apart at precise
5 frequencies. OFDM is one of the most spectrally efficient
6 transmission techniques. Among other advantages, multicarrier
7 OFDM systems have a much lower symbol rate than equivalent
8 single carrier systems.

9

10 In wireless channels, OFDM allows a system to mitigate
11 the effects of multipath propagation and to provide a high
12 data rate in the multipath environment. This technology is a
13 basis for the Wireless Local Area Network (WLAN) IEEE.802.11a
14 and IEEE.802.11g standards in the 5 GHz and 2.4 GHz frequency
15 bands, respectively. According to the standards, the 52-
16 carrier system provides up to 54 Mbit/s within a 20 MHz
17 bandwidth in a multipath environment with path delays up to
18 800 nanoseconds (ns). OFDM technology is recommended in an
19 IEEE 802.16 draft standard for fixed broadband wireless access
20 systems in the frequency range 2-11 Ghz. The draft standard
21 considers utilization of hundreds or even thousands of
22 orthogonal carriers with QAM modulation. OFDM is also
23 considered as a promising candidate for WLAN implementation in

1 the 60 GHz frequency band as well as for 3G mobile wireless
2 systems.

3

4 Typical OFDM applications are point-to-point and point-
5 to-multipoint (PTMP) transmissions. A point-to-multipoint
6 application is illustrated in Fig. 1 where a central station
7 (hub) and N user stations (nodes) are shown. The central
8 station may be a base station (BS) in a mobile or fixed
9 wireless network, or it may be an access point (AP) in a WLAN.
10 The nodes may be any individual devices of the wireless
11 network. For example, in the WLAN environment a node may be a
12 PC, a laptop computer, a printer, a VoIP cordless phone, etc.
13 Transmitted signals in the frequency domain are schematically
14 shown at the bottom of Fig. 1 and consist of M carriers,
15 numerated in the figure from 1 to M.

16

17 The key feature of the point-to-multipoint OFDM
18 application is that the Hub sends a signal to all nodes
19 simultaneously (in parallel), but only one of the nodes can
20 transmit signal within the current time interval. Fig. 1
21 shows the example in which only the i-th node is currently
22 transmitting a signal to the Hub, and only the i-th node is
23 allowed to use carriers for data transmission at the given

1 moment. The active node can utilize the set of all carriers
2 or any subset of carriers, but no other user can transmit any
3 carrier at the same time. Practically this means that the
4 system utilizes a type of time division access protocol, e.g.,
5 regular time division multiple access (TDMA) or random channel
6 access based on carrier sense multiple access (CSMA). In
7 other words, in PTMP applications, the nodes transmit their
8 data within different, non-overlapping time intervals.

9

10 Point-to-multipoint OFDM transmission has the benefit of
11 permitting the system to avoid the problems of differences in
12 signal powers, frequency offsets and time delays for signals
13 received from different nodes, because at any moment the
14 receiver processes the signal from a single transmitter only.
15 Therefore, the existing WLAN IEEE 802.11 standards support
16 only point-to-multipoint transmission. Even with an ad hoc
17 mode when there is no centralized controller-hub and one of
18 the nodes provides the function of a temporary hub, the IEEE
19 standard allows transmitting the signal only from one single
20 transmitter at any moment.

21

22 On the other hand, the point-to-multipoint mode cannot
23 efficiently exploit system capacity. For example, consider a

1 VoIP cordless phone as one of the nodes which does not need a
2 high data rate but which requires a high quality digital voice
3 transmission in real time. In this situation, when the
4 cordless phone is active, it uses only a small part of the
5 system capacity and forces all other nodes to wait for it to
6 get off the air.

7

8 One possible way to increase the efficiency of OFDM
9 utilization in a multi-user network is a multipoint-to-point
10 (MPTP) mode that allows the nodes to transmit data
11 simultaneously using a part of the system capacity for each
12 node. This approach is considered for WLAN applications based
13 on the IEEE 802.11a standard in McFarland, B. et al., "The 5-
14 UP Protocol for Unified Multiservice Wireless Networks", IEEE
15 Communications, Vol.39, No.11, November, 2001. A multipoint-
16 to-point mode is illustrated in Fig. 2, which contains the
17 same Hub and N nodes as in Fig.1.

18

19 The principal difference between multipoint-to-point OFDM
20 and point-to-multipoint OFDM is that in multipoint-to-point
21 OFDM all nodes have opportunity to send signal to the Hub
22 simultaneously (in parallel) using the corresponding parts of
23 a carrier set. As shown in the example of Fig. 2, the first

1 node (e.g., a cordless phone) transmits its data on the first
2 carrier, the second node transmits on the second and (M-5)-th
3 carrier, and so on. Distribution of carriers between the
4 nodes is a function of the hub. Practically, this
5 distribution, based on node demands, transforms the OFDM
6 technique into the orthogonal frequency division multiple
7 access (OFDMA) method.

8

9 In a real WLAN environment, OFDMA technology should be
10 combined with some type of time division multiple access
11 (TDMA). For example, if all carriers are currently distributed
12 and used within a subset of nodes and some additional nodes
13 demand communication, the system must assign some group of
14 carriers for two or even more nodes, and these nodes will use
15 the carriers in a time division mode.

16

17 OFDMA is an extended OFDM technique that provides the
18 most efficient exploitation of the multicarrier system
19 capacity. However, OFDMA has several additional issues as
20 compared to the traditional point-to-multipoint OFDM. At the
21 physical layer, all these issues are the result of differences
22 in signal transformation and the propagation in paths from
23 each individual node to the hub. As a result, groups of

1 carriers associated with different nodes have different
2 powers, different frequency offsets, and different time
3 delays. In addition, each carrier may have its own individual
4 phase shift. The corresponding issues can thus be formulated
5 as follows: 1) Power control for carrier groups; 2) Frequency
6 offset compensation for carrier groups; 3) Individual carrier
7 phase shift tracking; and 4) Time delay compensation for
8 carrier groups.

9

10 A general approach to a solution of the above issues is
11 described in McFarland, B. et al., "The 5-UP Protocol for
12 Unified Multiservice Wireless Networks", IEEE Communications,
13 Vol.39, No.11, November 2001. However, this paper does not
14 contain any details allowing a real implementation of the
15 system.

16

17 Methods and apparatus for power control in MPTP OFDM
18 systems (issue #1 above) based on data carrier duplication
19 were described in previously incorporated U.S. Serial No.
20 10/342,519 entitled "Method, Apparatus and System for OFDM
21 Power Control". In addition, pilotless methods, apparatus and
22 systems for frequency offset and phase shift tracking based on
23 phase correction in the frequency domain (after FFT) in the

1 hub receiver (issue #2 above) were proposed in previously
2 incorporated U.S. Serial No. 10/628,943 entitled "Pilotless,
3 Wireless, Telecommunications Apparatus, Systems and Methods".
4 However, neither of those disclosures provided a solution to
5 frequency offset compensation for carrier groups in MPTP OFDM
6 as the methods of frequency offset compensation disclosed in
7 U.S. Serial No. 10/628,943 only partly solves the problem.
8 The fact is that in the OFDM systems the frequency offset
9 causes both carrier phase shifts and violation of carrier
10 orthogonality. Violation of carrier orthogonality, in turn,
11 causes considerable intercarrier interference. The disclosed
12 algorithms in the previously incorporated patent applications
13 provide phase shift compensation in frequency domain (after
14 FFT), but they do not eliminate the intercarrier interference
15 in the FFT.

16

17 On the other hand, if all carriers are utilized by one
18 single node, then common frequency offset may be compensated
19 in the hub receiver in the time domain, i.e. before FFT, to
20 avoid the intercarrier interference. This approach is also
21 disclosed in previously incorporated U.S. Serial No.
22 10/628,943 for point-to-multipoint applications. However,
23 when different nodes use different groups (subsets) of

1 carriers simultaneously, and these groups have different
2 frequency offsets, then compensation of frequency offset in
3 the receiver in time domain is impossible.

4

5 One important aspect of frequency offset compensation in
6 MPTP OFDM systems is that the problem is preferably solved on
7 the basis of a "pilotless" approach; i.e., without the use of
8 pilot carriers during data transmission. The pilotless
9 approach allows a system to increase its real capacity.
10 Moreover, while a point-to-multipoint system could in
11 principle use fixed carriers as pilots, a MPTP pilot system
12 needs at least one pilot carrier for each carrier group; and
13 with respect to a flexible MPTP system, since the carrier
14 group configuration may be changed from session to session,
15 and the number of carriers within each groups is variable
16 (from one carrier to the maximum possible carriers), the pilot
17 approach is not a practical one for a flexible MPTP system
18 implementation.

19

20 It should be appreciated that two types of pilot signals
21 are usually used in wireless systems: preamble pilots which
22 are transmitted during preamble before data transmission, and
23 accompanying pilots which are transmitted during the whole

1 communication session in parallel with data transmission. In
2 accord with the present invention, a pilotless approach
3 permits use of the preamble pilots but does not utilize the
4 accompanying pilots during data transmission at all.

5

6 In the context of the frequency offset problem, the
7 preamble pilots provide rough compensation of the initial
8 frequency offset. For example, if a typical frequency
9 instability is equal to 20 ppm, then, in the frequency range 5
10 GHz, an up to 100 kHz frequency offset may be experienced. If
11 the frequency interval between adjacent carriers is about 200-
12 300 kHz, this offset cannot be compensated for during data
13 transmission because the receiver is not capable to
14 distinguish non-orthogonal carriers. So, for MPTP OFDM
15 systems, the initial frequency offset should be compensated
16 for in each transmitter within the initialization stage of the
17 communication session (handshake). This initial compensation
18 procedure, however, is outside the scope of the present
19 invention. Nonetheless, even if frequency offsets are
20 partially compensated during the handshake, the MPTP OFDM
21 system must provide precise frequency offset compensation
22 during the communication session in order to provide perfect

1 coherent signal processing. This precise frequency offset
2 compensation is an important part of MPTP OFDM system design.

3

4 SUMMARY OF THE INVENTION

5

6 It is therefore object of the invention to provide
7 multipoint-to-point, multicarrier, wireless, pilotless
8 telecommunication systems, apparatus and methods which
9 implement precise frequency offset compensation for carrier
10 groups associated with different users.

11

12 It is an additional object of the invention to provide
13 methods for the estimation of frequency offsets for carrier
14 groups in the hub receivers of multipoint-to-point,
15 multicarrier, wireless, pilotless telecommunication systems.

16

17 It is a further object of the invention to provide simply
18 implementable algorithms and apparatus for estimation of
19 frequency offsets for carrier groups in the hub receiver of a
20 multipoint-to-point, multicarrier, wireless pilotless
21 telecommunication system.

22

1 It is another object of the invention to provide methods
2 for determining desired parameters of the frequency offsets
3 for carrier groups, which should be transmitted from the hub
4 to user nodes for the corresponding frequency offset
5 correction in user transmitters.

6

7 An additional object of the invention is to provide
8 algorithms and apparatus for frequency offset compensation in
9 the user transmitters of multipoint-to-point, multicarrier,
10 wireless, pilotless telecommunication systems.

11 A further object of the present invention is to provide
12 multipoint-to-point, multicarrier, wireless, pilotless
13 telecommunication systems, apparatus and methods which combine
14 OFDMA and TDMA technologies to provide an efficient
15 utilization of system capacity in a multiuser environment.

16

17 In accord with these objects, which will be discussed in
18 detail below, the present invention provides methods,
19 apparatus and systems for compensation of frequency offsets
20 for carrier groups in the multipoint-to-point (MPTP),
21 multicarrier OFDM, wireless, pilotless telecommunication
22 systems. Broadly, the methods of the invention for
23 implementing frequency offset compensation in the MPTP OFDM

1 systems includes: in the hub receiver, estimating frequency
2 offset for each group of carriers in the frequency domain
3 (after FFT); transmitting the frequency offset parameters for
4 each group of carriers from the hub to the nodes; and in each
5 node transmitter implementing frequency offset compensation in
6 the time domain (after IFFT).

7

8 According to one aspect of the invention, algorithms of
9 frequency offset estimation for groups of carriers are
10 provided and are utilized by the hub receiver to support data
11 transmission from nodes to the hub. The algorithms are based
12 on reducing quadrature components or differential quadrature
13 components of the received carriers and averaging the reduced
14 components in two-dimensional space for K carriers within the
15 group and for N symbols of each carrier. The reduction
16 procedure involves all carriers utilized in the system and is
17 not dependent on their combining in the groups. The averaging
18 procedure on the other hand is carried out separately for each
19 carrier group participating in the session.

20

21 According to another aspect of the invention, simplified
22 algorithms of frequency offset estimation are provided for
23 groups of carriers. The simplified algorithms are based on

1 utilization of a simple reference vector as well as on a
2 majority vote algorithm which allows reduced components to be
3 replaced with their signs. Replacement of the reduced
4 components by their signs provides some mitigation of the
5 effect of wrong decisions, because in this case any wrong
6 decision cannot dramatically change the result. Additional
7 robustness of simplified algorithms is achieved by using a
8 lower bound for majority votes: if majority votes are less
9 than some predetermined threshold, no corrections are
10 provided.

11

12 Proposed estimates of frequency offsets are finally
13 expressed preferably as sine and cosine functions of the phase
14 shift caused by the frequency offset. These functions as well
15 as any their transformations may be considered as the desired
16 parameters of the frequency offset for the corresponding group
17 of carriers. According to the invention, these parameters are
18 transmitted from the hub to the node as a hub instruction for
19 current frequency correction.

20

21 According to another aspect of the invention, the
22 frequency offset compensation in the MPTP OFDM systems is
23 provided in each node transmitter. In particular, during a

1 current telecommunication session with the hub, each node
2 compensates its frequency offset as indicated by the hub by
3 means of signal correction in the frequency and/or time
4 domains. According to a preferred embodiment of the
5 invention, frequency offset compensation is accomplished in
6 the time domain based on linear transformation of complex
7 samples of a signal at the output of the IFFT in the
8 transmitter. Frequency offset compensation in the time domain
9 after IFFT is the preferred method for digital implementation
10 of the OFDM.

11

12 In accord with yet another aspect of the invention, the
13 MPTP OFDM system of the invention is provided with an
14 OFDMA/TDMA mode. In the MPTP OFDM system with combined
15 OFDMA/TDMA mode, if the system capacity is sufficient to
16 satisfy all current demands of the nodes in data transmission,
17 then carriers are distributed within the nodes, and pure OFDMA
18 mode is provided (using frequency offset compensation per
19 carrier group according to other aspects of the invention).
20 If the system capacity is not sufficient to satisfy all
21 current demands of the nodes in data transmission, then a
22 group of carriers is assigned to two or more nodes, and the

1 nodes utilize the group of carriers within non-overlapped time
2 intervals according to any type of TDMA mode.

3

4 BRIEF DESCRIPTION OF THE DRAWINGS

5

6 Figure 1 is a high level schematic diagram of an OFDM
7 point-to-multipoint mode telecommunication system of the prior
8 art.

9

10 Figure 2 is a high level schematic diagram of an OFDM
11 multipoint-to-point mode telecommunication system of the prior
12 art.

13

14 Figure 3 is a high level schematic diagram of the
15 proposed multipoint-to-point (MPTP) OFDM system with frequency
16 offset compensation.

17

18 Figure 4 is a detailed schematic diagram of the Hub-site
19 of the proposed MPTP OFDM system, including frequency offset
20 estimation procedure for the carrier groups, based on
21 differential quadrature components of the received carriers.

22

1 Figure 5 is a detailed schematic diagram of the Hub-site
2 of the proposed MPTP OFDM system, providing simplified
3 frequency offset estimation procedure for the carrier groups,
4 based on the majority algorithm.

5

6 Figure 6 is a detailed schematic diagram of the User-site
7 of the proposed MPTP OFDM system, providing frequency offset
8 compensation in time domain for the carrier group in the node
9 transmitter.

10

11 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

12

13 Turning now to Fig. 3, a high-level block diagram of a
14 multipoint-to-point OFDM system 10 according to the invention
15 is seen. The system 10 implements frequency offset
16 compensation as will be described hereinafter. The system 10
17 is comprised of a hub 20 and a plurality of nodes (two shown)
18 40a, 40b. The hub includes a hub transmitter 22, a hub
19 receiver 24, and a fast Fourier transform block 26 and an
20 estimation block 28 which may be considered as part of the hub
21 receiver. Each of the plurality of nodes 40a, 40b includes a
22 node receiver 42a, 42b, a node transmitter 44a, 44b, and an
23 inverse fast Fourier transform block 46a, 46b and a correction

1 block 48a, 48b which may be considered as part of the node
2 transmitter.

3

4 In the MPTP OFDM system of the invention, each node
5 (user) 40 has the opportunity to transmit data using a group
6 of carriers (the "group" being as small as a single carrier
7 and as large as all carriers), depending on its data rate
8 demand and assignment from the hub 20. If all carriers were
9 to be utilized by a single node, then a common frequency
10 offset could be compensated for in the hub receiver in the
11 time domain, i.e., before use of the FFT. In this case, the
12 compensation algorithm is described as follows: Let S_m be the
13 m-th complex sample of the received multicarrier symbol,
14 frequency shifted by Δf Hz, where m is an integer changing
15 from 1 to M, and M is the number of carriers in the
16 multicarrier OFDM signal; then, the m-th sample of the
17 compensated (frequency unshifted) signal S_{mc} is the complex
18 number defined by

19

20 $S_{mc} = S_m \exp(-jm\phi)$ (1.1)

21

22 where $\phi = 2\pi\Delta f T$, and T is an FFT interval (interval of OFDM
23 orthogonality).

1

2 However, when different nodes use different groups
3 (subsets) of carriers simultaneously, and these groups have
4 different frequency offsets, then compensation of frequency
5 offset in the receiver in the time domain is impossible. In
6 this case, and in accord with the invention, the compensation
7 procedure is transferred to the transmitting nodes 40 which
8 are correspondingly informed by the hub 20 regarding values of
9 the frequency shifts within the carrier groups. In any
10 individual node providing data transmission on a specified
11 group of carriers, the samples at the output of the IFFT 46 of
12 the node should be corrected by the correction block 48 as
13 required by the hub 20.

14

15 Correction of the samples at the IFFT output in the
16 transmitter can be provided according to equation (1.1), but
17 in this case S_m will be the m -th complex sample of the
18 transmitted signal at the output of IFFT, and S_{mc} will be the
19 m -th sample of the compensated (frequency unshifted) signal in
20 the transmitter. A detailed description of the corresponding
21 algorithm is provided below with reference to Fig. 6.

22

1 So, according to the invention, a method of frequency
2 offset compensation in MPTP OFDM systems includes steps of: in
3 the hub 20, estimating the frequency offset in the frequency
4 domain (i.e., after FFT) for each group of carriers;
5 transmitting the frequency offset parameters for each group of
6 carriers from the hub 20 to the nodes 40; and in each node,
7 accomplishing frequency offset compensation in the time domain
8 (i.e., after IFFT). This method is implemented in the system
9 of Fig. 3 with the frequency domain estimation of frequency
10 offsets for all carrier groups accomplished in the estimation
11 block 28 of the hub 20, and the frequency offset compensation
12 (i.e., correction of complex samples of the carrier groups)
13 accomplished in the correction blocks 48 of the nodes 40.

14

15 More particularly, during a telecommunication session
16 between the hub 20 and the nodes 40, the hub 20 receiver 24
17 receives all transmitted carriers (as transmitted by the
18 transmitters 44 of the nodes 40), and after their FFT
19 transformation by FFT block 26, uses its estimation block 28
20 to provide a two-dimensional (in time and frequency domains)
21 estimation of frequency offset parameters for all carrier
22 groups (subsets of carriers) associated with different nodes
23 participating in the session (as described in more detail

1 hereinafter with reference to Figs. 4 and 5). Then, the hub
2 uses its transmitter 22 to transmit to all nodes 40 parameters
3 of their frequency offsets as estimated. The nodes 40 receive
4 the parameters via their receivers 42, and after inverse fast
5 Fourier transform into the time domain via IFFT 46, each node
6 compensates its frequency offset by means of the signal
7 correction block 48 in the time domain.

8

9 It should be noted that during a current
10 telecommunication session, each node 40 can also compensate
11 its frequency offset in the frequency domain or in both
12 frequency and time domains (as will be described hereinafter),
13 but the correction blocks 48a, 48b of Fig. 3 shows only time
14 domain correction after IFFT, which is the presently preferred
15 embodiment of the invention from an implementation point of
16 view.

17

18 As previously mentioned, according to the invention it is
19 desirable to conduct a frequency offset estimation at the hub
20 for each carrier group utilized by different nodes 40 for
21 data transmission to the hub 20. According to the preferred
22 embodiment of the invention, the frequency offset estimation
23 algorithms utilized are based on reducing and averaging

1 quadrature components or differential quadrature components of
2 the received carriers. Two different frequency offset
3 estimation algorithms are shown in flow-chart format in Figs.
4 and 5.

5

6 Before turning to Fig. 4, it is useful to provide the
7 mathematical basis for the frequency offset estimation
8 algorithms. In particular, if X_{kn} and Y_{kn} are quadrature
9 components of the received n-th symbol of the k-th carrier,
10 then the differential components of the n-th symbol of the k-
11 th carrier dX_{kn} and dY_{kn} are calculated as follows:

12

$$13 \quad dX_{kn} = (X_{kn} - X_{dkn}), \quad (2.1a)$$

$$14 \quad dY_{kn} = (Y_{kn} - Y_{dkn}), \quad (2.1b)$$

15

16 where X_{dkn} , Y_{dkn} are quadrature components of a decision for the
17 n-th symbol of the k-th carrier, which typically corresponds
18 to a constellation point nearest to the received vector
19 (X_{kn}, Y_{kn}) .

20

21 Given the differential components of equations (2.1a) and
22 (2.1b), the reduced differential components dX_{rkn} and dY_{rkn} of

1 the n-th symbol of the k-th carrier are determined according

2 to

3

4 $dX_{rkn} = (A_0/A_{kn}) (dX_{kn}\cos\Delta_{kn} - dY_{kn}\sin\Delta_{kn}), \quad (2.2a)$

5 $dY_{rkn} = (A_0/A_{kn}) (dY_{kn}\cos\Delta_{kn} + dX_{kn}\sin\Delta_{kn}), \quad (2.2b)$

6

7 where Δ_{kn} is the phase difference between the decision vector
8 for the n-th symbol of the k-th carrier and the reference
9 vector, A_{kn} is the amplitude of the decision vector for the n-
10 th symbol of the k-th carrier, and A_0 is the amplitude of the
11 reference vector. It should be noted that, conceptually, any
12 two-dimensional vector can be considered as the reference
13 vector. In practice, however, some reference vectors may be
14 more convenient than others. Two reference vectors in
15 particular may have practical advantage: the first being a
16 reference vector coinciding with one of the constellation
17 points, and the second being a reference vector coinciding
18 with X-axis or Y-axis in the two-dimensional space (e.g.,
19 vector $(1,0)$ or $(0,1)$).

20

21 Just as the differential quadrature components of
22 equations (2.1a) and (2.1b) can be reduced as in equations
23 (2.2a) and (2.2b), quadrature components of the received

1 carriers X_{kn} and Y_{kn} may also be directly reduced to the
 2 corresponding components X_{rkn} and Y_{rkn} of the reference vector:

3

4 $X_{rkn} = (A_0/A_{kn}) (X_{kn}\cos\Delta_{kn} - Y_{kn}\sin\Delta_{kn}), \quad (2.2c)$

5 $Y_{rkn} = (A_0/A_{kn}) (Y_{kn}\cos\Delta_{kn} + X_{kn}\sin\Delta_{kn}) . \quad (2.2d)$

6

7 The reduced differential components dX_{rkn} and dY_{rkn} as well
 8 as reduced quadrature components X_{rkn} and Y_{rkn} may be averaged
 9 both in the time domain and in the frequency domain, i.e.,
 10 through indexes n and k , correspondingly. If the considered
 11 group of carriers has a common frequency shift, then a result
 12 of averaging in time and frequency domains will be to detect
 13 this common frequency shift.

14

15 A general expression for the two-dimensional averaging of
 16 reduced differential components dX_{rkn} and dY_{rkn} within a group
 17 of K carriers on N symbol intervals for each carrier can be
 18 presented as follows:

19

20 $dX_r = (1/KN) \sum dX_{rkn} = (A_0/KN) \sum_{k=1}^K \sum_{n=1}^N (dX_{kn}\cos\Delta_{kn} - dY_{kn}\sin\Delta_{kn}) / A_k \quad (2.3a)$

21 $dY_r = (1/KN) \sum dY_{rkn} = (A_0/KN) \sum_{k=1}^K \sum_{n=1}^N (dY_{kn}\cos\Delta_{kn} + dX_{kn}\sin\Delta_{kn}) / A_k \quad (2.3b)$

1

2 Likewise, the reduced quadrature components of the
 3 received carriers X_{rkn} and Y_{rkn} from (2.2c) and (2.2d) may be
 4 averaged according to:

5

6
$$X_r = (1/KN) \sum X_{rkn} = (A_0/KN) \sum_{k=1}^K \sum_{n=1}^N (X_{kn} \cos \Delta_{kn} - Y_{kn} \sin \Delta_{kn}) / A_{kn}, \quad (2.3c)$$

7
$$Y_r = (1/KN) \sum Y_{rkn} = (A_0/KN) \sum_{k=1}^K \sum_{n=1}^N (Y_{kn} \cos \Delta_{kn} + X_{kn} \sin \Delta_{kn}) / A_{kn}, \quad (2.3d)$$

8

9 As will be appreciated by those skilled in the art, the
 10 averaging procedure of equations (2.3) involves components of
 11 K carriers and N symbols for each carrier. The values
 12 utilized for K and N preferably depend on the required number
 13 of averaged components necessary and sufficient for reliable
 14 estimates. For example, if R is the desired number of
 15 averaged components for a reliable estimate, then

16

17 $R=KN.$

18 (2.4)

19

20 Simulations of OFDM systems in typical WLAN conditions
 21 show that $R \approx 50$ is generally sufficient for a precise

1 estimation of frequency offset. Thus, according to one
2 preferred aspect of the invention,

3

4 $KN \approx 50$.

5 (2.5)

6 Those skilled in the art will appreciate that the number
7 N of averaged symbols thus depends on the size K of the
8 carrier group. A first extreme case is where the carrier group
9 contains sufficient numbers of carriers such that N can equal
10 1. In this case averaging can be completely provided in the
11 frequency domain. A second extreme case is where a group
12 contains a single carrier (i.e., $K=1$). In this case,
13 averaging is completely provided in the time domain.

14

15 The estimates X_r and Y_r from equations (2.3c) and (2.3d)
16 are approximate coordinates of a new reference vector, shifted
17 relative to the initial one because of frequency offset, and
18 the estimates dX_r and dY_r from (2.3a) and (2.3b) are
19 approximate coordinates of the difference between the shifted
20 reference vector and the reference vector. These estimates
21 (X_r and Y_r or dX_r and dY_r) permit the expression of a phase
22 shift caused by the frequency offset as a phase angle ϕ .

23

1 Taking into account that the shifted reference vector has
2 coordinates $X_0 + dX_r$ and $Y_0 + dY_r$, where X_0 and Y_0 are coordinates
3 of the reference vector, trigonometric functions of the phase
4 ϕ can be derived as follows:

5

$$6 \quad \text{Sin}\phi = [(X_0 + dX_r) Y_0 - (Y_0 + dY_r) X_0] / A = [dX_r Y_0 - dY_r X_0] / A,$$

$$7 \quad (2.6a)$$

$$8 \quad \cos\phi = [(X_0 + dX_r)X_0 + (Y_0 + dY_r)Y_0]/A = [(A_0)^2 + dX_r X_0 + dY_r Y_0]/A, \quad (2.6b)$$

10

11 where $A = A_0 * [(X_0 + dX_r)^2 + (Y_0 + dY_r)^2]^{0.5}$. If, for example, the
12 reference vector has coordinates $X_0=1$ and $Y_0=0$, then equations
13 (2.6a) and (2.6b) reduce as follows:

14

$$15 \quad \sin\phi = -dy_r/A \quad (2.6c)$$

$$16 \quad \cos\phi = (1 + dx_z)/A \quad (2.6d)$$

17

18 If the amplitude change of the reference vector (due to noise)
19 is negligible, then equations (2.6c and (2.6d) further reduce
20 according to

2-

$$22 \quad \sin \Phi \approx -dy_x \quad (2.6e)$$

$$23 \quad \cos\Phi \approx 1 \quad (2.6f)$$

1

2 As will be appreciated by those skilled in the art, the
3 trigonometric functions of phase ϕ can also be derived through
4 estimates X_r and Y_r from equations (2.3c) and (2.3d) as
5 follows:

6

$$7 \quad \text{Sin}\phi = (X_r Y_0 - Y_r X_0) / A, \quad (2.7a)$$

$$8 \quad \text{Cos}\phi = (X_r X_0 + Y_r Y_0) / A, \quad (2.7b)$$

9

10 where $A = A_0 [(X_r)^2 + (Y_r)^2]^{0.5}$. If, for example, the reference
11 vector has coordinates $X_0=1$ and $Y_0=0$, then equations (2.7a) and
12 (2.7b) reduce as follows:

13

$$14 \quad \text{Sin}\phi = -Y_r / A, \quad (2.7c)$$

$$15 \quad \text{Cos}\phi = X_r / A. \quad (2.7d)$$

16

17 If the amplitude change of the reference vector (due to noise)
18 is negligible, then equations (2.7c) and (2.7d) further reduce
19 to

20

$$21 \quad \text{Sin}\phi \approx -Y_r, \quad (2.7e)$$

$$22 \quad \text{Cos}\phi \approx 1. \quad (2.7f)$$

23

1 Estimates (2.6) and (2.7), which are the sine and cosine
2 functions of the phase shift caused by the frequency offset,
3 may be considered as the desired parameters of the frequency
4 offset for the corresponding group of carriers. According to
5 the invention, these parameters are transmitted from the hub
6 20 to the node 40 utilizing the corresponding group of
7 carriers.

8

9 It should be appreciated that any other transformations
10 of estimates (2.6) and (2.7) can be also used as the
11 parameters of the frequency offset and be transmitted from the
12 hub to the nodes. For example, functions $\text{Sin}\phi$ and $\text{Cos}\phi$ can be
13 combined into one single number for transmission to the
14 corresponding node:

15

$$16 \quad \phi = \operatorname{arctg}(\operatorname{Sin}\phi/\operatorname{Cos}\phi). \quad (2.8)$$

17

18 In turn, the phase parameter of equation (2.8) can be
19 transformed into a frequency parameter and expressed in Hz:

20

$$21 \quad \Delta f = \phi / 2\pi T \quad (2.9)$$

22

1 Given the above, according to the invention, a preferred
2 general algorithm for frequency offset estimation comprises
3 (the algorithm being described in parallel for both
4 differential quadrature components and quadrature components
5 of the received signal):

- 6 1) After FFT in the hub receiver, a set of quadrature
7 components X_{kn} and Y_{kn} of the received carriers at the n-th
8 symbol interval is used for making multicarrier current
9 decisions X_{dkn} and Y_{dkn} , and differential quadrature components
10 of the carriers dX_{kn} and dY_{kn} are calculated according to
11 equation (2.1);
- 12 2) Using the current decisions, the set of differential
13 quadrature components dX_{kn} , dY_{kn} or the set of quadrature
14 components X_{kn} , Y_{kn} is reduced according to equation (2.2) for
15 all carriers;
- 16 3) Reduced differential quadrature components dX_{rkn} , dY_{rkn} or
17 reduced quadrature components X_{rkn} , Y_{rkn} are averaged within each
18 group of carriers associated with different users in the
19 frequency domain (K carriers of a group) and in the time
20 domain (N symbols of each carrier) to find estimates of a
21 differential reference vector dX_r , dY_r or a reference vector
22 X_r , Y_r for each carrier group according to equation (2.3);

1 4) Using estimates of the differential reference vector dX_r
2 , dY_r , or reference vector X_r , Y_r , trigonometric functions of
3 phase shifts for each carrier group are calculated according
4 to equations (2.6) or (2.7); and
5 5) Upgraded parameters of frequency offsets for carrier groups
6 according to equations (2.6), (2.7), (2.8), or (2.9) or their
7 transformations, are transmitted by the hub transmitter to all
8 nodes participating in the session.

9

10 The general algorithm for frequency offset estimation
11 based on differential quadrature components of the received
12 carriers is illustrated in Fig. 4, which shows a block and
13 flow diagram of the hub 20 of the MPTP OFDM system 10. In
14 Fig. 4, bold lined blocks carry out the frequency offset
15 estimation algorithm, while the remaining blocks are a
16 conventional part of the receiver. It should be noted that
17 the FFT unit 26, the multicarrier decision unit 102, the
18 differential components calculator 104, and the soft decoder
19 106 are shown apart from the hub receiver 24 so that their
20 connections to the estimating procedure can be more easily
21 seen, as their signals are partly used in the algorithm.

22

1 The conventional part of the hub receiver operates as
2 follows. Digital samples of the n-th received multicarrier
3 symbol are fed to the FFT unit 26. Complex numbers (X_{kn}, Y_{kn})
4 for the whole set of carriers from the output of the FFT are
5 fed to multicarrier decision unit 102 where current decisions
6 (X_{dkn}, Y_{dkn}) for all carriers are made. Decisions (X_{dkn}, Y_{dkn}) are
7 typically used for the calculation of differential quadrature
8 components (dX_{kn}, dY_{kn}) of the received carriers by calculator
9 104 according to equation (2.1), which, in turn, are used in
10 the soft decoder 106. Corrected symbols from the soft decoder
11 are then fed to output circuits (not shown) of the hub
12 receiver 24.

13

14 According to the invention, the differential quadrature
15 components (dX_{kn}, dY_{kn}) calculated by differential components
16 calculator 104 are reduced at 111 according to equations
17 (2.2a) and (2.2b). The reduction procedure also utilizes
18 parameters of signal reduction Δ_{kn} , A_0 , A_{kn} or their
19 combinations such as A_0/A_{kn} stored in the parameters memory
20 113. Additionally, the reduction procedure can utilize
21 exclusion of unreliable symbols from the further processing as
22 described in previously incorporated U.S. Serial No.
23 10/628,943. The exclusion signal (if applied) is provided by

1 the unreliable symbols exclusion block 115 located between the
2 soft decoder 106 and the reduction unit 111. The unreliable
3 symbols exclusion block 115 utilizes information regarding
4 symbol reliability from the soft decoder 106.

5

6 It should be noted that the reduction procedure 111
7 involves all carriers utilized in the system and does not
8 depend on their combination in carrier groups. In contrast to
9 the reduction procedure, the averaging procedure 117 is
10 carried out separately for each carrier group participating in
11 the session, according to equations (2.3a) and (2.3b). For
12 each carrier group averaging can involve different numbers of
13 carriers K and different numbers of symbols N. The averaging
14 unit 117 provides estimates dX_r and dY_r (i.e., approximate
15 coordinates of the difference between the shifted reference
16 vector and the reference vector) for each carrier group.
17 These estimates are then utilized by the phase shift
18 estimation block 119 to generate functions of the phase ϕ
19 according to equations (2.6) for each carrier group (e.g.,
20 $\text{Sin}\phi$ and $\text{Cos}\phi$). These functions may then be modified in block
21 121 as in equations (2.8) or (2.9) to provide indications of
22 the phase shift for each carrier group which are fed to the

1 hub transmitter 22 to be transmitted to the nodes 40 as a hub
 2 instruction for current frequency correction.

3

4 As previously suggested, the general algorithm for
 5 frequency offset estimation as described with reference to
 6 Fig. 4 can be simplified. The simplification of frequency
 7 offset estimation algorithm for carrier groups is based on the
 8 fact that, if the reference vector is chosen carefully, the
 9 trigonometric functions of phase reduce and can be represented
 10 in other manners. For example, if the reference vector is
 11 chosen to be $(1, 0)$, then a sign of the Y-coordinates of the
 12 reduced differential vectors or corrected reference vectors
 13 coincides with a sign of the received vectors phase shift, and
 14 the phase shift is proportional to the absolute value of the
 15 Y-coordinates of the vectors. So, using equations (2.6e) and
 16 (2.7e),

17

18 $\sin\phi \approx -dY_r = (A_0/KN) \sum_{k=1}^K \sum_{n=1}^N (dY_{kn} \cos\Delta_{kn} + dX_{kn} \sin\Delta_{kn}) / A_{kn}.$ (2.10a)

19 $\sin\phi \approx Y_r = (A_0/KN) \sum_{k=1}^K \sum_{n=1}^N (Y_{kn} \cos\Delta_{kn} + X_{kn} \sin\Delta_{kn}) / A_{kn},$ (2.10b)

20

21 $\sin\phi$ values may then be directly utilized as desired
 22 parameters of frequency offset or they can be used as the

1 basis for transformed parameters such as the transformed
2 parameters set forth in equations (2.8) and (2.9).
3

4 Further simplification of frequency offsets estimation
5 for carrier groups is based on majority vote approach where
6 the accumulation of terms in equations (2.10a) or (2.10b) is
7 replaced by an accumulation of their signs. The procedure
8 includes two steps: simplified reduction of the received
9 vectors for all carriers, and accumulation of signs of the
10 reduced components for carrier groups.

11

12 The simplified reduction procedure includes only the Y -
13 coordinate of the reduced vector and only one decision
14 parameter Δ_{kn} :

15

16 $dY_{rkn} = (dY_{kn}\cos\Delta_{kn} + dX_{kn}\sin\Delta_{kn}) , \quad (2.11a)$

17 $Y_{rkn} = (Y_{kn}\cos\Delta_{kn} + X_{kn}\sin\Delta_{kn}) . \quad (2.11b)$

18

19 Signs of the reduced components (2.11a) or (2.11b) are then
20 accumulated (majority votes) for each carrier group according
21 to
22

1 $D_{+-} = \sum_{k=1}^K \sum_{n=1}^N \text{Sign} (dY_{kn} \cos \Delta_{kn} + dX_{kn} \sin \Delta_{kn}), \quad (2.12a)$

2 $D_{+-} = \sum_{k=1}^K \sum_{n=1}^N \text{Sign} (Y_{kn} \cos \Delta_{kn} + X_{kn} \sin \Delta_{kn}), \quad (2.12b)$

3

4 where $\text{Sign}(x) = +1$ or -1 . The resulting integer D_{+-} is the
 5 difference between the number of components with positive
 6 phase shifts and a number of components with negative phase
 7 shifts. This integer reflects carrier majority vote, and its
 8 sign determines a direction for frequency offset adjustment.

9

10 The integer value obtained pursuant to equations (2.12a)
 11 and (2.12b) can serve as a parameter of frequency offset for
 12 the corresponding carrier group. In this case, the value
 13 should be transmitted to the node transmitter and utilized for
 14 offset compensation.

15

16 It should be noted that replacement of terms in equations
 17 (2.10) by their signs in equations (2.12) provides some
 18 mitigation of the effect of wrong decisions, because with the
 19 use of signs, wrong decisions cannot dramatically change the
 20 result. Additional robustness of equations (2.12) may be
 21 achieved by using a lower bound for majority votes. For
 22 example, if the modulo of D_{+-} is less than some predetermined

1 threshold T_d , no corrections are provided. The threshold T_d
2 may be chosen to depend on the number of components in
3 equations (2.12), which is preferably equal to KN . According
4 to a preferred aspect of the invention, a threshold equal to
5 approximately 10% of all components participating in averaging
6 is utilized and is believed to provide a desired robustness to
7 the system.

8

9 Since integer D_{+-} from equations (2.12) determines only a
10 direction of frequency offset adjustment, it is desirable also
11 to obtain a value (size) of the adjustment. Different
12 mechanisms for obtaining frequency offset compensation value
13 are available. A first mechanism involves averaging
14 projections of the component majority. In this mechanism,
15 differential carrier projections or carrier projections are
16 accumulated as in equations (2.10) only for components from
17 the majority votes, and then the resulting value is divided by
18 the number of majority components. For example, if the total
19 number of components is equal to KN , then the number of
20 majority components is equal to $(KN + |D_{+-}|)/2$. In other words,
21 in this mechanism the frequency offset is corrected by the
22 projections corresponding to the largest number of occasions.

1 It should be noted that the method has shown good results in
2 the system simulation.

3

4 Another mechanism of determining the frequency offset
5 value is based on an assumption that the frequency is slowly
6 changing and can be efficiently corrected by changing the
7 carrier frequency with a constant small increment. In this
8 case the frequency offset estimation algorithm should
9 determine only a direction of the adjustment. In turn, the
10 adjustment direction $\text{Sign}(\phi)$ can be found as a sign of value
11 D_{+-} from (2.12):

12

13 $\text{Sign}(\phi) = \text{Sign} \left[\sum_{k=1}^K \sum_{n=1}^N \text{Sign} (dY_{kn} \cos \Delta_{kn} + dX_{kn} \sin \Delta_{kn}) \right], \quad (2.13a)$

14 $\text{Sign}(\phi) = \text{Sign} \left[\sum_{k=1}^K \sum_{n=1}^N \text{Sign} (Y_{kn} \cos \Delta_{kn} + X_{kn} \sin \Delta_{kn}) \right], \quad (2.13b)$

15

16 It should be noted that the mechanism of changing the
17 carrier frequency with a constant small increment is the
18 simpler of the two mechanisms because it does not require a
19 calculation of the frequency shift value. Its disadvantage,
20 on the other hand, is that it cannot provide the precise
21 proper constant increment for a wide range of frequency
22 offset.

1

2 Based on the above, the simplified algorithm of frequency
3 offset estimation can be described as follows (the algorithm
4 is described in parallel for both differential quadrature
5 components and quadrature components of the received signal):

6 1) After a FFT in the hub receiver, a set of quadrature
7 components X_{kn} and Y_{kn} of the received carriers at the n-th
8 symbol interval is used for making multicarrier current
9 decisions X_{dkn} and Y_{dkn} , and differential quadrature components
10 of the carriers dX_{kn} and dY_{kn} are calculated according to
11 equations (2.1);

12 2) Using the decisions, the set of differential quadrature
13 components dX_{kn} , dY_{kn} or the set of quadrature components X_{kn} ,
14 Y_{kn} is reduced according to equations (2.11) for all carriers;

15 3) Signs of the reduced differential quadrature components
16 dY_{rkn} or reduced quadrature components Y_{rkn} are accumulated
17 within each group of carriers associated with different users,
18 in the frequency domain (K carriers of a group) and in time
19 domain (N symbols of each carrier), and then transformed into
20 an integer D_+ according to majority vote algorithm according
21 to equations (2.12);

22 4) If D_+ is more than some predetermined threshold T_d , the
23 direction of frequency correction is determined by the sign of

1 D.. according to equations (2.13), and the frequency offset
2 value is determined to equal either the average offset of the
3 majority components or a predetermined constant increment;
4 5) The upgraded parameters of frequency offsets for the
5 carrier groups (i.e., the sign of the frequency adjustment and
6 the frequency offset values for the carrier groups) are
7 transmitted by the hub transmitter to all nodes participating
8 in the session.

9

10 The simplified algorithm of frequency offset estimation
11 is illustrated in the block and flow diagram of Fig. 5. As in
12 Fig. 4, the bold lined blocks of Fig. 5 carry out the
13 frequency offset estimation algorithm of the invention in the
14 receiver of the hub 20, while the remaining units (the FFT 26,
15 the multicarrier current decision unit 102, the differential
16 components calculator 104, and the soft decoder 106) are part
17 of a conventional hub receiver. Operation of this
18 conventional part of the receiver was described above with
19 reference to Fig. 4.

20

21 Operation of the frequency offset estimate blocks of Fig.
22 5 is as follows. Differential quadrature components
23 (dX_{kn}, dY_{kn}) determined by block 104 are subjected to simplified

1 reduction at 131 according to equations (2.11). The reduction
2 procedure 131 utilizes parameters of signal reduction Δ_{kn}
3 stored in the parameters memory 114. It should be noted that
4 the reduction procedure involves all of the carriers utilized
5 in the system and is not dependent on their combination in
6 groups. In contrast to the reduction procedure, the vote
7 procedure at 133 according to equations (2.12) is carried out
8 separately for each carrier group participating in the
9 session. Calculation of a final sign at 135 according to
10 equations (2.13) for each group can involve different numbers
11 of carriers K and different numbers of symbols N. Finally,
12 upgraded parameters of frequency offset are fed to the hub
13 transmitter 22 to be transmitted to the nodes 40 as a hub
14 instruction for current frequency correction.

15

16 As previously suggested, according to the invention, the
17 frequency offset compensation information (i.e., the
18 parameters) for the MPTP OFDM system is provided by the hub 20
19 to each node 40. Thus, during a current telecommunication
20 session with the hub, each node compensates its frequency
21 offset as indicated by the hub by means of a signal correction
22 in the frequency and/or time domain.

23

1 There are different approaches to frequency correction in
2 a radio transmitter. A traditional approach consists in the
3 proper change of local oscillator frequency by Δf Hz
4 determined via equation (2.9). In digital implementations of
5 the OFDM algorithm, the preferable method for frequency
6 correction is frequency offset compensation in the time domain
7 after IFFT. This method can be described as follows. Let X_m
8 and Y_m be the real and imaginary parts of the m -th complex
9 sample of a signal at the output of the IFFT in the node
10 transmitter, where m is an integer changing from 1 to M , and M
11 is the number of carriers in the multicarrier OFDM signal.
12 Also assume that the signal is frequency shifted by Δf Hz.
13 Then, taking into account equation (1.1), the real and
14 imaginary parts X_{mc} and Y_{mc} of the m -th corrected sample are
15 equal to

16

$$17 \quad X_{mc} = X_m \cos(m\phi) + Y_m \sin(m\phi) , \quad (3.1a)$$

$$18 \quad Y_{mc} = Y_m \cos(m\phi) - X_m \sin(m\phi) , \quad (3.1b)$$

19

20 where $\phi = 2\pi\Delta f T$, and T is an FFT interval.

21

22 It should be noted that in real computation algorithms,
23 the product $m\phi$ in brackets of equations (3.1) is calculated

1 modulo 2π . Further computation of $\cos(m\phi)$ and $\sin(m\phi)$ is
2 typically provided by means of the stored table of sine and
3 cosine functions within a 2π interval.

4

5 Implementation of equations (3.1) is illustrated in Fig.
6, which shows a detailed schematic diagram of the user-site
7 (node) 40 of the MPTP OFDM system 10 of the invention,
8 including the frequency offset compensation procedure in the
9 time domain for the carrier group utilized by the node. In
10 the block-diagram of Fig. 6, the bold lined units carry out
11 the frequency offset compensation algorithm of the invention.
12 The remaining units such as the IFFT 162 and the modulator 164
13 are conventional parts of the OFDM transmitter which are shown
14 separately from the node transmitter 42 so that their
15 connections to the compensation algorithm is more evident.

16

17 The frequency offset compensation algorithm is
18 implemented using a phase multiplier "m ϕ " 170, a table of Sine
19 and Cosine functions 172, and a correction of complex samples
20 block 174. During the session with the hub 20, the node 40
21 receives a frequency-offset parameter for its carrier group.
22 In Fig. 6 the parameter is shown as a phase shift $\phi = 2\pi\Delta fT$.
23 This phase shift is modulo 2π multiplied at 170 by numbers

1 $m=1,2, \dots, M$, where M is a total number of carriers in the
2 system and m increases synchronously with the corresponding
3 samples at the output of the IFFT 162. The multiplied phase
4 $m\phi$ is fed to a Sine and Cosine functions table 172 which
5 provides sine and cosine values to the correction block 174.
6 Correction block 174 corrects the complex samples (X_m, Y_m)
7 generated by the IFFT according to equations (3.1). The
8 corrected complex samples (X_{mc}, Y_{mc}) are fed to the transmitter
9 modulator 164. With the provided corrections, the modulator
10 164 may then properly modulate all input data signals to be
11 transmitted by the node transmitter 44 to the hub.

12

13 It should be noted that during a current
14 telecommunication session with the hub 20, each node 40 can
15 compensate its frequency offset in the frequency domain or in
16 the time domain or in both the frequency and time domains.
17 According to a preferred aspect of the invention, the initial
18 frequency offset is roughly compensated in the frequency
19 domain, while precise frequency offset tracking is provided in
20 the time domain. More specifically, during a handshake
21 between a hub and a node the hub receives a pilot signal from
22 the node and roughly measures the frequency offset of this
23 particular node transmitter. In the handshake period of time

1 (before data transmission) the hub can assign a special set of
2 carriers (group of carriers) for the node or the group of
3 carriers may be predetermined for the node. In any case,
4 during the handshake or preamble the hub transmits a frequency
5 offset parameter to the node, and the node compensates using
6 the indicated frequency shift in the frequency domain, for
7 example, by changing the reference oscillator frequency. This
8 provides a rough compensation of frequency offset. Then,
9 during data transmission (the session), the precise
10 compensation of the frequency offset is provided based on the
11 previously described methods of the invention; i.e., the hub
12 estimates the frequency offset for the carrier group,
13 transmits frequency offset indications to the node, and the
14 node compensates for the offset in the time domain.

15

16 According to another aspect of the invention, all of the
17 previously described procedures for frequency offset
18 compensation may be utilized in either a pure OFDMA mode or in
19 a combined OFDMA/TDMA mode. In the pure (typical) OFDMA mode,
20 the hub distributes all carriers or a subset of carriers among
21 the nodes currently participating in a communication session,
22 and all groups of carriers associated with different nodes are
23 subjected to frequency offset compensation according to the

1 proposed algorithms. In the combined OFDMA/TDMA mode, some
2 group of carriers or part of a group (e.g., even a single
3 carrier) can be assigned for utilization in two or more nodes.
4 In this case, the nodes utilize the same carrier(s) within
5 different time intervals according to a regular TDMA schedule
6 indicated by the hub, or according to random channel access
7 based, for example, on carrier sense multiple access (CSMA).
8 In the combined OFDMA/TDMA mode, the frequency offset
9 compensation procedure differs from the frequency offset
10 compensation procedure of the pure OFDMA mode in substantially
11 one only aspect: a subset of carriers utilized by two or more
12 nodes is subjected to frequency offset compensation separately
13 for each node associated with that subset of carriers. As a
14 result, the hub must estimate frequency offsets not only for
15 each group of carriers but also for each node utilizing the
16 same group of carriers.

17

18 It will be appreciated by those skilled in the art that
19 the flow charts of Figures 3-6 may be implemented in hardware,
20 software, firmware, dedicated circuitry or programmable logic,
21 digital signal processors, ASICs, or any combination of them.

22

1 There have been described and illustrated herein several
2 embodiments of methods, systems and apparatus for pilotless
3 frequency offset compensation in multipoint-to-point wireless
4 systems with OFDM. While particular embodiments of the
5 invention have been described, it is not intended that the
6 invention be limited thereto, as it is intended that the
7 invention be as broad in scope as the art will allow and that
8 the specification be read likewise. Thus, while particular
9 reference vectors have been disclosed as preferred, it will be
10 appreciated that other reference vectors could be utilized as
11 well. In addition, while particular frequency offset
12 parameters were described as preferred for transfer from the
13 hub to the nodes, it will be understood that other parameters
14 (i.e., indications of frequency offset) could be provided.
15 Also, while embodiments of the invention have been shown in
16 the drawings in flow-chart format with particular function
17 blocks, it will be recognized that the functionality of
18 various of the blocks could be split or combined without
19 affecting the overall approach of the invention. Further,
20 while the invention was disclosed with reference to a soft
21 decoder, it will be appreciated that a hard decoder could be
22 utilized alone or in conjunction with the soft decoder, and
23 that one or the other will suffice. It will therefore be

1 appreciated by those skilled in the art that yet other
2 modifications could be made to the provided invention without
3 deviating from its spirit and scope as claimed.

4